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Relationship between Cosmic rays' Modulation and Solar Wind Parameters in Solar Cycle 24 and Ascending Phase of Cycle 25

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Abstract: The solar cycle 24 behaviour of several heliospheric parameters and activity indices is contrasted with the persistent changes in cosmic rays throughout time. Previous to this, a series of was used for the geomagnetic indices Ap, Kp, and aa, solar flare group counts, cosmic ray strengths during solar cycles 22, 23, and 24, and sunspot counts. We found the interrelationships between solarheliospheric factors such the interplanetary magnetic field, cosmic-ray modulation, the present solar cycle, which is marked by several rare and powerful solar occurrences, and the heliospheric current sheet tilt, using this model. We show that these parameters may be used together to replicate most of the modulation potential fluctuations that occur throughout this cycle. Observed variations in cosmic ray fluxes every eleven years are mostly due to variations in solar activity, which also occur every eleven years. In addition to this, every about eleven years, the heliosphere and solar polar regions experience a reversal of the orientations of their magnetic fields. Also, this adds features to the acknowledged ~11-cycle and causes an extra 22-year solar magnetic cycle to exist. Looking at the correlations, time delays, and temporal patterns of cosmic-ray intensity versus various parameters from 1996 to 2022, the cycle's distinctive traits are discovered to be strange. Intervals for correlational analysis and obtained hysteresis curves from cycle pro are also included.

Keywords: Interactions Between the Sun, Geomagnetic Field, Cosmic Rays

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INTRODUCTION

Spacecraft and high-altitude aircraft routine operations, as well as the health of flight crew and astronauts, are jeopardized by these particles, which constitute the majority of the space radiation environment (e.g., Mertens & Slaba 2019). The fast expansion of the solar wind (SW) has created an uneven bubble-like structure in the heliosphere, which is full with energetic particles. The most common kinds of extraplanetary rays (EPRs) are those that travel between planets, those that travel between galaxies, and those that are abnormal in nature.

A lot of work has gone into studying the sun's effect on galactic cosmic rays (GCR), particularly in order to gauge the sun's ever-changing behaviour. The fast expansion of the solar wind (SW) has created an uneven bubble-like structure in the heliosphere, which is full with energetic particles. The most common kinds of extraplanetary rays (EPRs) are those that travel between planets, those that travel between galaxies, and those that are abnormal in nature, which occurs when the sun's polarity flips near its maximum in each activity cycle. A number of studies have focused on the polarity dependent effects on cosmic rays.

Almost as fast as light, charged particles known as cosmic rays travel from space to Earth. Atomic nuclei of elements In the periodic chart, from the lightest to the heavyest groups make up the vast bulk of cosmic rays. The term "galactic" describes these objects since they are dispersed across the Milky Way and originate from outside our solar system. Nuclei and electrons, among other energetic particles, are driven by solar flares and cosmic rays as they travel through interplanetary space and the Sun. Within the Milky Way, these particles have an energy range from 100 MeV to 10 GeV. When magnetic field of the planet interacts with a shock wave from the solar wind, it causes a transient disruption of the magnetosphere that is called a geomagnetic storm or magnetic storm. Ejections of solar wind that begin in coronal holes are known CIRs and CMEs, which are zones of co-rotating interaction, in the vicinity of solar physics. A magnetic storm might be triggered by any of these occurrences. Geomagnetic storms happen at varying frequencies depending on the sun's cycle. The majority of geomagnetic storms are caused by solar maximum, which is when CMEs, or coronal mass ejections, occur most often.

LITERATURE REVIEW

Gushchina (2014) throughout Cycle 24, Being the cycle with the lowest solar activity (SA) throughout the period of consistent ground-based observations since 1951 allowed us to examine oscillations in the intensity of cosmic rays (CR). over long periods of time, as did the exceptionally deep SA minimum that occurred between cycles 23 and 24. The CR density for both low- and medium-energy particles over the aforementioned 2009 timeframe exceeds the intensity maximum, the value of which is energy dependant. From cycles 19 to 23, this density was seen. During the SA growth phase from 2010 to 2012, there was much less CR modulation compared to the corresponding SA growth stages of previous cycles following 2009. This anomaly in CR fluctuations was investigated by looking at the likely explanations, which include changes in SA features during this time and a minimum value for the CR residual modulation between cycles 23 and 24. It has been computed the contribution of various solar magnetic field indices and properties accounting for irregular solar activity.

Mishra (2016) For an abnormally extended period (July 2008–August 2009), the SSN have maintained their minimal level. Oulu NM has not seen cosmic rays of this strength since the previous solar minimum in April 1964, when ground-based detectors detected them. The highest SSN value for this cycle is likewise quite low compared to others dates (19–23). However, for cycle 23, it's 13–14 months. Researchers have also looked at how the running cross correlation function behaves throughout this solar cycle and discovered that, unlike in past cycles, it stays at its maximum value of about -0.8 to -0.9 for a very long time. Additionally, for both cycles, there is a strong correlation between the fluctuation of SSN and SSA (r >.92). The unusual behaviour of solar cycle 24 has prompted a discussion and comparison of cosmic ray modulation trends with previous cycles.

Kumar (2022) Previous work employing it predicted highest amplitudes and cycle onset times in the 19–24 range. The following is a synopsis of the comforting results achieved via all of these revisions: Predictions on the defining parameters of cycle 24 were previously made using an upgraded version of the suggested approach. Preliminary predictions for cycle 24's properties are validated using the observed values of spotless events. In addition, this approach may be used to anticipate the 25th solar cycle's maximum amplitude and ascension period. Our predictions for the next 25 cycles are based on the stacking LSTM forecasting model. Results from our investigation show that our model successfully anticipates data patterns and long-term interdependence. With an amplitude of 171.9 3.4 sunspots, When compared to solar cycle 24, the maximum intensity of cycle 25 will be 47% greater.

Opm (2015) The 24th solar cycle is one of the weakest since Cycle 23 ended with a protracted and profound minimum.The period between the solar minimum and minimax is characterised by an increase in solar activity. Using we examine the variations in cosmic-ray intensity throughout three distinct epochs with varying kinds and degrees of activity: a deep minimum, a rising activity phase and a mini maximum, taking into account solar activity, heliospheric plasma and field characteristics. At both ends, the lowest and maximum, Using We investigate the impact of stiffness on modulation using neutron monitor data collected from stations throughout the globe. Throughout all three stages of the event, we analyse independently the lag time between cosmic-ray intensity and certain solar and interplanetary characteristics. At the same time, we examine the three-stage modulation of cosmic-ray intensity by several parameters, one of which is the present sheet tilt. We also go over the consequences of our findings and how important each is.

Bhattacharya (2014) Certain solar parameters include the sunspot number, planetary index, and solar radio flux solar activity characteristics that influence adjustments to the cosmic ray intensity (CRI). In order to see how various characteristics are correlated with CRI, we look at how CRI changes over the phases 21–24 of the solar cycle, both rising and falling. It seems that SRF and SSN are both potential excellent indicators for long-term regulation of CRI.

RESEARCH METHODOLOGY

The outcomes are evaluated using a variety of data science and statistical methods. A number of graphs, charts, plots, and links have been investigated for studies of cosmic ray modification in the near and far futures. Our tool of choice will be regression analysis. One way to find out how related a dependent variable is to a group of independent variables is to use regression analysis. As a descriptive data analysis approach, regression analysis does not need any assumptions on the data production procedures. We looked at data from 1996–2022, which encompasses the upturn portions of solar cycles 22–24 and 25, to compare cosmic ray intensity (CRI) with solar/geomagnetic activity. Below are some of the many reasons why the geomagnetic Ap index is so important for tracking solar activity over the long term. References: (Lee and Fisk 1981; Kane 2007). The following variables were utilised to do this: geomagnetic disturbance index (Ap), solar wind velocity (V), magnetic field (B), and sunspots (Rz). The modulation parameter, shown as V * B, is determined by multiplying the interplanetary magnetic field strength (b) with the solar wind plasma velocity (V). Oulu (0.81 GV), Moscow (2.41 GV), and Beijing (9.56 GV) were the three neutron monitoring sites that we utilised in this study for CRI data. Monthly averages are calculated using data obtained from many sources for solar and geomagnetic factors.

Information Regarding Sun and Heliospheric Magnetic Fields as well as Cosmic Rays

The upper limit of the atmospheric cascade curve on Earth, where the temporal dependence of CR fluxes, Nm, are shown in Figure 1. Secondary particles are these. Primary CRs, consisting of protons and nuclei, exceeding the geomagnetic threshold stiffness Rc by rigidities R descend to Earth's surface, where they are created. The fluctuation in CR fluxes during the last eleven years is well seen in Figure 1.

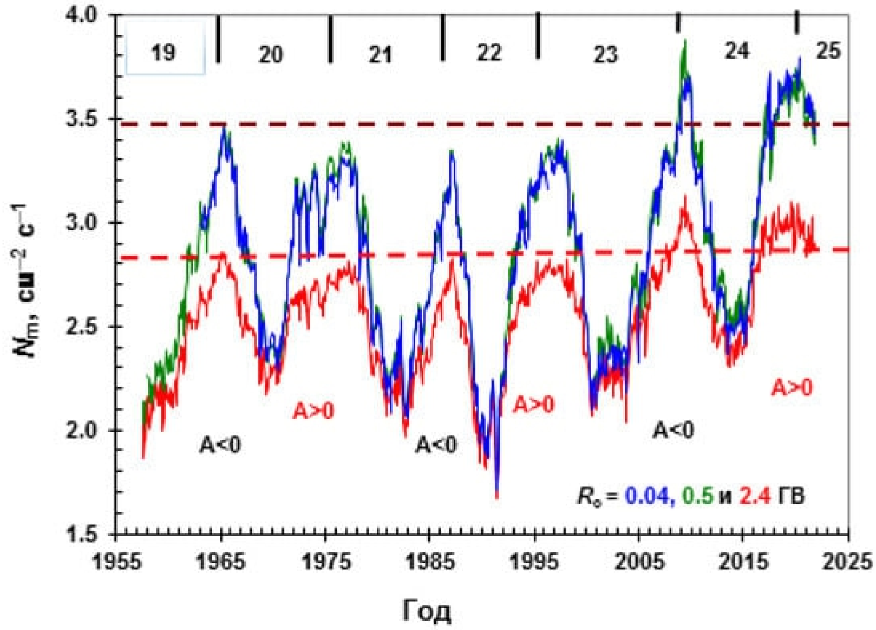


Figure 1. Numbers at the top of the chart represent how CR fluxes vary with time throughout 19–25 solar activity cycles (Nm, monthly mean).

Data for the north pole area was retrieved from the Apatity station in the zone of Murmansk, information about the southern polar zone was acquired from the Antarctic station Mirny, and information about the central northern region was retrieved from the Moscow station. The maximum CR fluxes at different latitudes in 1965 are shown by the dashed red and brown lines. A In this 22-year solar magnetic cycle, the integers reflect (A > 0) and A < 0, which indicate the different stages of the cycle. To get more information, read the book. When A > 0, it signifies the positive phase, while when A < 0, it signifies the negative phase.

The accompanying fluctuations of CR fluxes are caused by solar activity cycles every eleven years. The maximum CR flux is recorded around one year after the lowest solar activity. As particle energies or the geomagnetic cutoff stiffness, Rc, rise, the magnitude of the 11-year oscillations of CRs diminishes. By comparing the CR fluxes measured at the same latitude in 1990 (when solar activity was at its peak) and 1996 (when it was at its lowest), for instance, one may make use of the information shown in Figure 1. When Rc is low, the In Figure 1, the green and blue curves illustrate the lowest and greatest values of Nm, respectively. This difference is higher than the red curve, which shows the comparable values of Nm at middle latitude with Rc = 2.4 GV. Compared to the solar cycles that came before it (19–23 solar cycles), the lowest levels of solar activity in cycles 24 and 25 were much lower. During these cycles, the highest fluxes of CRs (about 2009 and 2021) were recorded over the duration of their observations, one year after the solar activity minimums.

Similar to the solar polar caps, the heliosphere keeps its magnetic field directions and alignments constant during the whole twenty-two-year magnetic cycle, at least while the sun's magnetic field isn't in motion inverts.

It will be shown later on that the heliosphere CR fluxes are strongly affected the orientations of the lines that make up the magnetic field. A 22-year cycle of solar magnetic flux exhibits a flat pattern during positive phases (A > 0) and a peaked temporal dependency of cosmic rays (A < 0) in Figure 1. Negative phases often have larger CR fluxes than positive ones.

Figure 2 depicts from the positive (a) to the negative (b) phases of the 22-year solar magnetic cycle, the heliospheric magnetic field directions and the drift velocities of protons, positrons, antiprotons, and electrons.

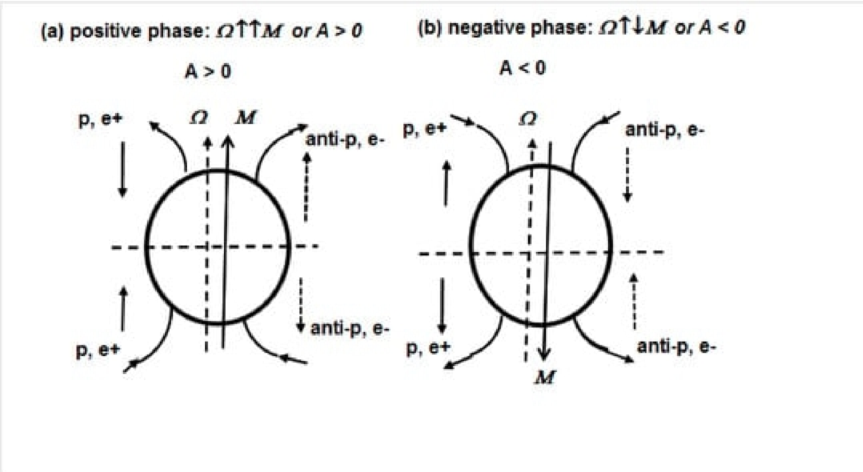


Figure 2. Sun and heliosphere magnetic fields are seen during the positive (a) and negative (b) stages of the 22-year solar magnetic cycle, respectively. Here we see the Sun represented by a huge circle.

Because The direction of a particle's drift is controlled by the sign of its electric charge. current, it was previously believed that particle drift was cause the temporal dependences in CRs to have a peak and a plateau shape. What determines a particle's drift velocity is the direction of lines in a field of magnetic fields and the direction of electric charge. This 22-year solar magnetic cycle is shown schematically in Figure 3, which also shows the dependent CR fluxes with time for the positive (A > 0) and negative (A < 0) phases.

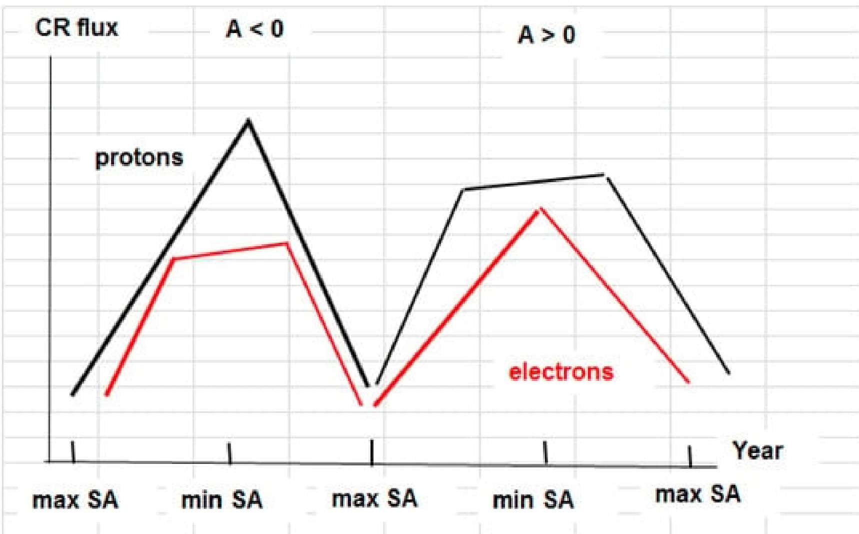


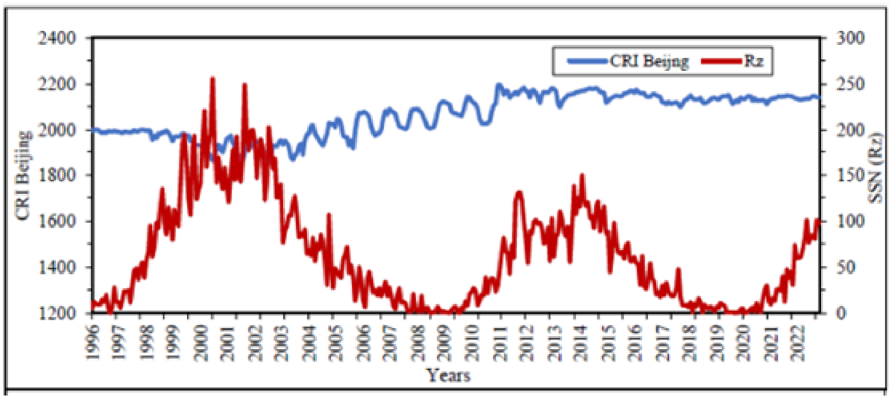
Figure 3. When In the positive (A > 0) or negative (A < 0) phase of the 22-year solar magnetic cycle, cosmic ray fluxes with positive electric charges are presentare shown by the black curve, while the negative electric charges are represented by the red curve. Time intervals between SA maximum and SA minimum, which are both 11 years long, stand for the solar activity cycles, which are the times of highest and lowest solar activity. ~Eleven years separates consecutive maximum SA (minimum SA).

Figure 3 shows that During the low solar activity era, when the 22-year solar magnetic cycle is in its negative phase (A < 0), the flux of CRs with a positive electric charge reaches its highest. according to the present theoretical idea. A plateau is seen for positively charged particles during the positive portion of the cycle (A > 0). The inverse is true for negatively charged particles (red curve).

We may compare the experimental results with the theoretical ideas by doing an analysis.

DATA ANALYSIS

The solar-terrestrial interaction provides a possible explanation for the galactic cosmic ray fluctuations of 11 and 22 years. The solar cycle is shown to affect the cosmic ray intensity (sunspot numbers Rz), with maximal intensity sunspot minima seven months later. But this trend isn't always followed by solar cycles. It is the solar cycle that dictates how long it takes for cosmic ray cycles to lag behind solar cycles. It is also affected by the stage of the solar cycle. Both the sunspot count and cosmic ray intensity have been previously investigated. It was found that the strength of cosmic rays is directly related to the number of sunspots. According to Draper and Smith (1998), there was a correlation between sun illumination (Rz) and cycles 23 and 24 of the astronomical beam force (CRI). Specifically, the correlational study used the average yearly benefits of the super-neutron screens in Beijing, Oulu, and Moscow. From 1996 to 2022, the quantity of sunspots is inversely related to infinite beams. Using the mean yearly estimates of sunspot numbers (Rz) and infinite beam force, a correlation coefficient was constructed from 1996 to 2022, encompassing solar cycles 22 and 24. Figure 4 shows that when the sun is very active, the CRI from Beijing goes up. According to Figure 5, over the 22-24 solar cycles, the CRI and Rz, B, and V had an anti-correlation of -0.60, -0.3, and -0.3, respectively.



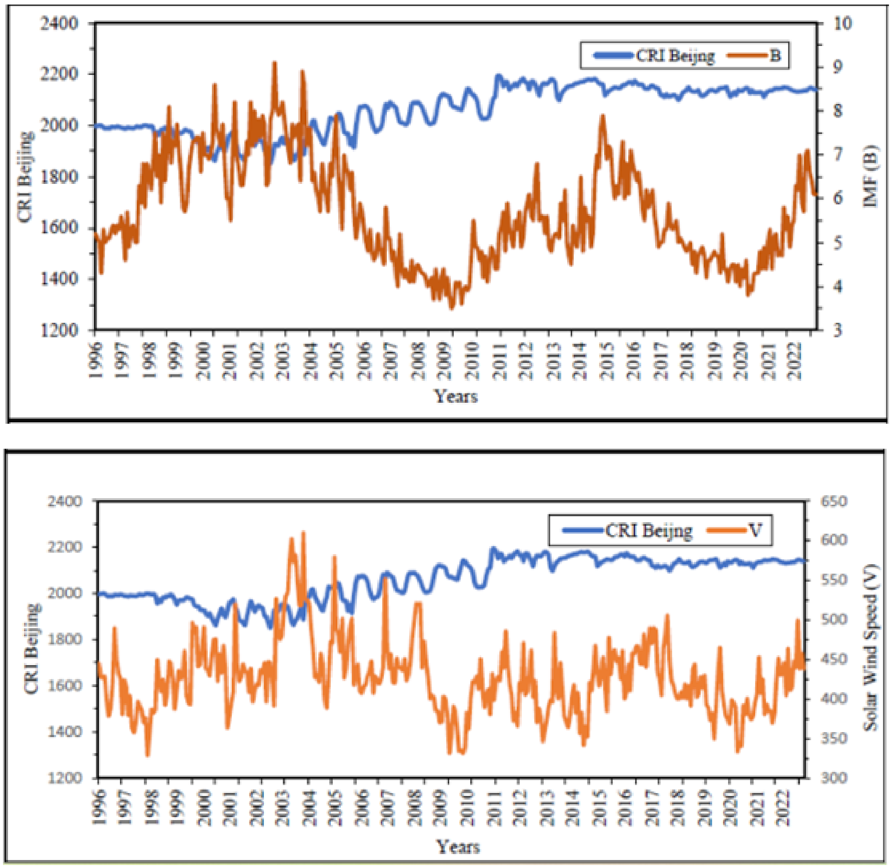
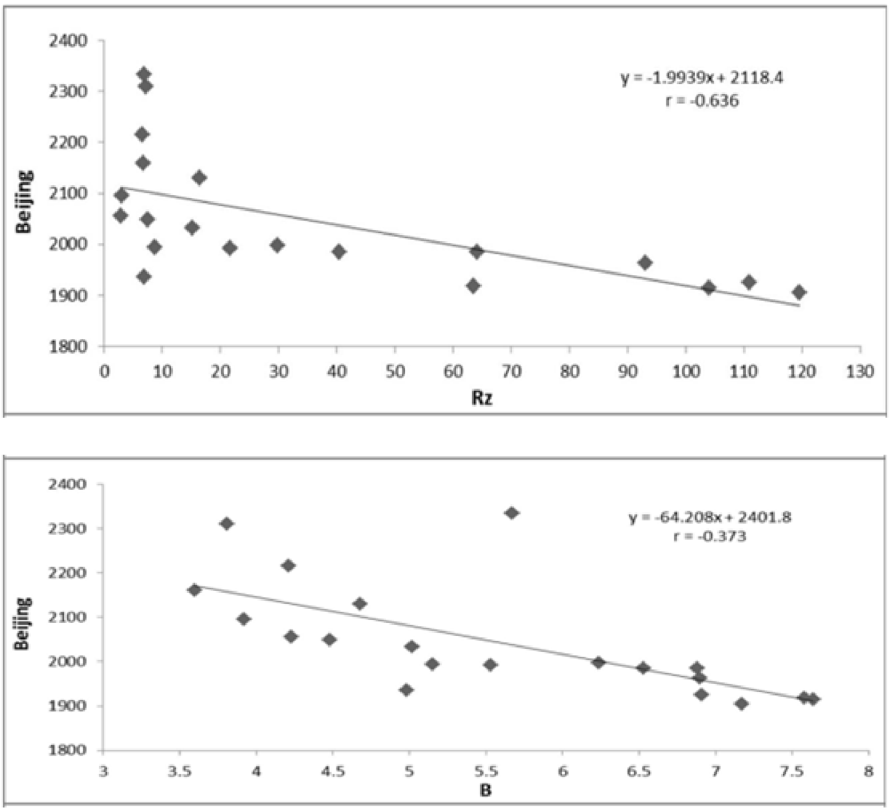


Figure 4. For span of 1996–2021, geomagnetic sunspot activity, cosmic ray intensity count, solar wind speed, and field will be recorded at stations in Beijing.



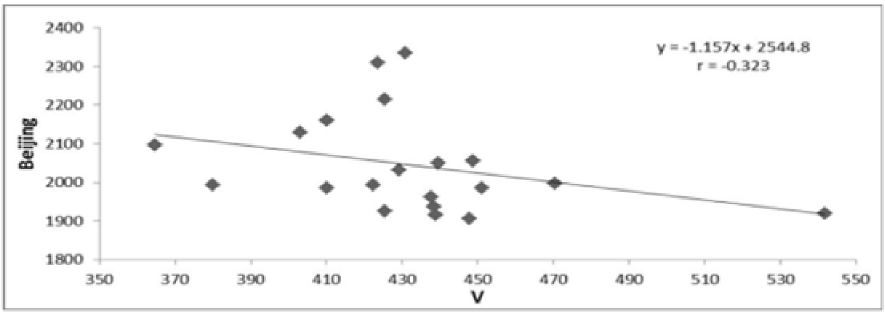


Figure 5. From 1996 to 2021, the following variables were plotted: variables: solar wind velocity (V), geomagnetic field (B) and sunspot number (Rz) in relation to Beijing.

Modulation of Cosmic Rays by Solar and Heliospheric Factors

Numerous The modification of cosmic rays by the heliosphere is affected by solar and heliospheric factors. (As stated by Ferreira and Potgieter 2017). Observed shifts in the solar wind and magnetic field, which are indicators of solar activity, significantly alter cosmic rays. When the sun is at its most active, its magnetic field is stronger, allowing the interstellar medium to better deflect cosmic rays and speeding up the solar wind. According to Moraal and Potgieter (2015), cosmic rays that penetrate the inner solar system see a decrease in strength at these periods.

Solar Cycles and Alteration of Cosmic Rays

The sun's rotation, which occurs every eleven years, has a substantial impact on cosmic ray modulation (Potgieter 2013). During solar maximum, when the sun's magnetic field is strongest and the heliosphere is expanding, cosmic rays are less because the sun is so active. As the sun isn't actively heating up the solar system, cosmic rays can go deeper into it., such as solar minimums. There is some variation in cosmic-ray modulation throughout the cycle, but measurements show that it is strongest around solar peak (2019, Strauß). When the sun's cycles change, it affects the heliospheric and solar parameters, impact the complex patterns of cosmic-ray modulation.

Heliospheric Magnetic Field and Current Sheet

The heliospheric current sheet and magnetic field have a substantial impact on the trajectory of cosmic rays. When the solar wind meets the Sun's magnetic field, it forms an area of enhanced magnetic turbulence called the heliospheric current sheet. This structure is large-scale in nature. When charged cosmic rays collide with the chaotic magnetic field of the current sheet, they begin to disperse and diffuse (Usoskin & Kovaltsov 2020). In the end, this process alters cosmic rays, which changes their energy spectrum and strength as they pass through the heliosphere. Space missions and space weather considerations. The relationship between cosmic-ray modulation and solar and heliospheric characteristics is crucial for safe space mission operations and precise space weather forecasts. During periods of increased cosmic-ray flow, astronauts and spacecraft are particularly at risk of radiation exposure from galactic cosmic rays. By monitoring and predicting patterns of cosmic-ray modulation, space organisations may prepare for and execute missions with enough shielding and safeguards to mitigate risks caused by high cosmic-ray intensity.

Comparison of Experimental Data and Theory

Electrons in CRs have been the subject of much experimental study for quite some time. We can see how protons and electrons rely on time.

The secondary Figure 6 displays the CR fluxes noted in the Earth's atmosphere during the Pfotzer-Regener maximum, ΔNm, plotted against time. The initial protons and nuclei that generated these secondary particles had rigidities ranging from 0.73 to 2.4 GV, and their energy ranged from 250 to 1500 MeV. Figure 6 shows the data used to calculate ΔNm, which are the differences in Nm values observed at latitudes where the 0.5 and 2.4 GV are the geomagnetic cutoff rigidities, respectively, respectively. Furthermore, the electron intensities are shown in Figure 6. Primary protons and nuclei create secondary particles in Earth's atmosphere with amplitudes of temporal variations that are similar to those of primary electrons.

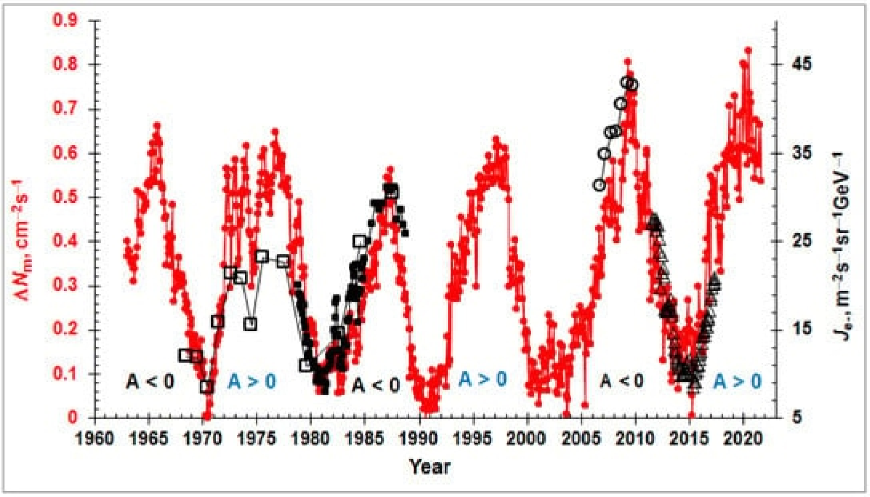


Figure 6. The red dots on the left vertical axis represent the values of the average monthly fluxes of charged particles in the atmosphere for more information, refer to the text) at the peak of the cascade curve, ΔNm. Results from space experiments conducted aboard the International Space Station, including the PAMELA and AMS-02 programs, and electron data from balloons are represented by open squares, black squares, open cycles, and open triangles, respectively, on the right vertical axes. In addition, the main electron intensities are displayed, ranging from 0.9 to 1.1 GeV. As A > 0 and A < 0, the positive and negative signs represent the negative phases of the 22-year solar magnetic cycle, respectively, respectively.

Figure 6 shows that cosmic rays generated by primary protons and nuclei had a temporal dependency similar to a plateau from 1974 to 1978 (red curve). Even for electrons, this temporal dependency resembled a plateau. Particles with positive and negative electric charges showed peak-like temporal dependences between 1983 and 1988 and 2007 and 2012, respectively. These findings go counter to the conclusion drawn in and contemporary theoretical notions on CR modulation in the heliosphere.

Time dependences in CRs that seem like peaks and plateaus cannot be explained by the drifts of charged particles, both positively and negatively, as seen in Figure 6. For particles with positive and negative

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charges alike, we may see temporal dependences that resemble peaks and those that resemble plateaus.

Modulation of Electrons and Positrons. High-Energy Cosmic Rays

The magnetic spectrometers with the help of AMS-02 and PAMELA, the electron and positron primary fluxes in space missions. So, it's possible to analyses the particle modulation processes when the sun goes through cycles of 11 and 22 years. We investigate relative electron and positron densities at R = 1.0-1.2 GV as an example. Figure 7 shows how these particle fluxes vary over time.

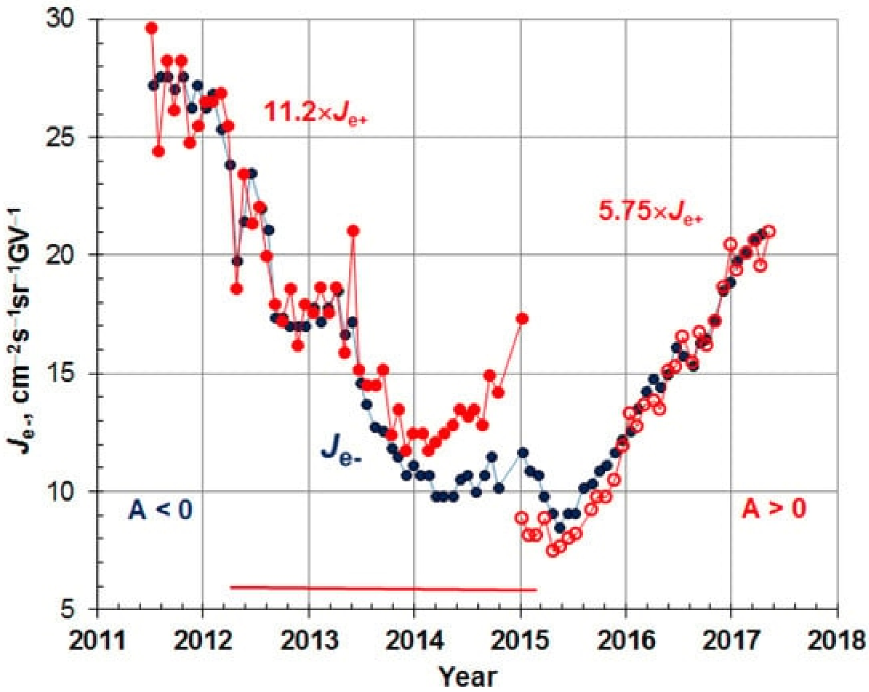

Figure 7. Depending on the rigidity R = 1.0-1.2 GV, the electron (black points) and positron (red points) intensity change over time. Between 2011 and 2015, on the upslope from 2011 to 2013, the positron intensity was set to match the electron intensity in response to changes in solar activity: One and a half Je+ is equal to 11.2 Je-. Also calculated for the declining solar activity branch (2015–2017) was Je-= 5.75 Je+. In order to normalise, the years 2017–2017 were utilised. 4-The inversion of the solar polar magnetic field happened for the whole period depicted by the horizontal red line.

Between The the positron and electron energies changed in tandem during the course of 2011–2013 and 2016–2017, respectively, as seen in Figure 7. Separate stages of the sun's magnetic cycle are reflected in the two epochs. When A is less than 0, the first period is linked to the negative phase, and when A is more than 0, the second period is linked to the positive phase.

CONCLUSION

Solar and heliospheric forces influence the heliosphere's modification of cosmic rays, which is an intriguing field of research with major implications for space weather, space exploration, and astrophysics. This comprehensive review focusses on the critical role About solar flares and how heliospheric magnetic fields affect cosmic-ray propagation, as well as the most significant findings and theoretical underpinnings modification by cosmic rays. As our knowledge cosmological-ray modulation increases, we will be better equipped to probe space's depths and grasp the interconnectedness of the heavens both inside and beyond our solar system. The impending solar cycle's magnitude is strongly correlated with the frequency of very calm geomagnetic days. Incorporating cycle 25 of the sun's life cycle after cycles 23 and 24 increased its activity and demonstrated its impact on space weather. According to statistical models, 2013 is projected to see a high of 50 to 70 sunspots each month. Models that account for According to sun polar magnetic field intensity, the highest point may happen as soon as 2012. It would be interesting to see how cycle 25 develops in comparison to later cycles. In the first scenario, cosmic rays are able to freely enter the heliosphere and lines of solar and galactic magnetic fields re-connect, which is known as an open heliosphere (A 0, M). Cosmic rays have a peak-like temporal dependency. In the second scenario, when the heliosphere is closed and A > 0, There is no reconnection of the lines of solar and galactic magnetic fields. The magnetic barrier, which extends from the termination shock (at around 85 au.) to the heliopause, is an obstacle that cosmic rays must overcome before they can reach their final destination. (at about 125 au.). before they can reach the heliosphere. In cosmic rays, the temporal dependency is similar to a plateau.

References

1. Bhattacharya, R. & Roy, Misha. (2014). Link between Cosmic Ray Intensity and Solar Activity During Different Phases of Solar Cycles. 5. 72-74.

2. Opm, Aslam & Badruddin, B. (2015). Study of Cosmic-Ray Modulation During the Recent Unusual Minimum and Mini-Maximum of Solar Cycle 24. Solar Physics. 290. 10.1007/s11207-015-0753-5.

3. Kumar, Pawan & Pal, Mahender & Rani, Amita & Mishra, A. & Singh, Sham. (2022). Modulation of Cosmic Ray with Solar activities During Solar Cycles 19-24 to forecast Solar Cycle 25. 10.21203/rs.3.rs-2070605/v1.

4. Mishra, V. & Mishra, A. (2016). Study of solar activity and cosmic ray modulation during solar cycle 24 in comparison to previous solar cycle. Indian Journal of Physics. 90. 10.1007/s12648-016-0895-9.

5. Gushchina, R. & Belov, A. & Eroshenko, E. & Obridko, V.N. & Paouris, Evangelos & Shelting, B. (2014). Cosmic Ray Modulation during the Solar Activity Growth Phase of Cycle 24. Geomagnetism and Aeronomy. 54. 430-436. 10.1134/S0016793214040057.

6. Potgieter, M. S. (2013). The solar modulation of cosmic rays. Living Reviews in Solar Physics, 10(3), 1-115. doi:10.12942/lrsp-2013-3

7. Usoskin, I. G., & Kovaltsov, G. A. (2020). Heliospheric modulation of cosmic rays: A review. Journal of Space Weather and Space Climate, 10, 35. doi:10.1051/swsc/2020034

8. Moraal, H., & Potgieter, M. S. (2015). Modulation of galactic cosmic rays: The heliosphere and heliosheath. Journal of Geophysical Research: Space Physics, 120(9), 7461-7480. doi:10.1002/2015JA021237

9. V.K Mishra & A. P. Mishra, Long-Term Modulation of Cosmic-Ray Intensityand Correlation Analysis Using Solar and HeliosphericParameters, Solar Phys 293:141 (2018)

10. Singh, S., Mishra, A.P. Cosmic ray intensity increases during high solar activity period for the solar cycles 22 and 23. Indian J Phys 93, 139–145 (2019)

11. Sham Singh, A. P. Mishra, interaction of solar plasma near-earth with reference to geomagnetic storms

during maxima of solar cycle 24, Indian J Phys. 1227-1234 (2015)

12. Ross, E., Chaplin, W.J. The Behaviour of Galactic Cosmic-Ray Intensity During Solar Activity Cycle 24. Sol Phys 294, 8 (2019). https://doi.org/10.1007/s11207-019-1397-7